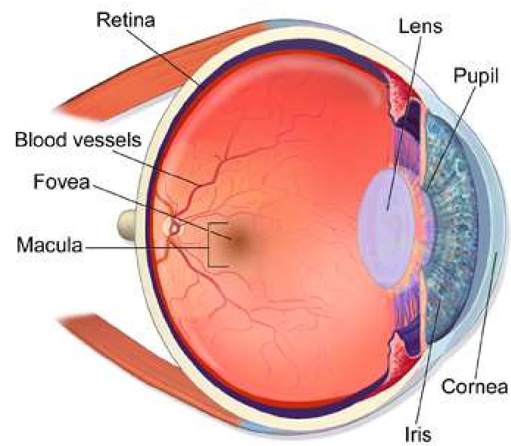
WHITE PAPER: SOLIDDD'S PARALLEL-RAY OPTICS AND OUR DISCOVERY OF HUMAN SINGLE-EYE STEREOPSIS

1. Fly's Eye Stereopsis in Humans



Eye Anatomy by BruceBlaus

It is well understood that the brain constructs stereo perception by combining information from two normal eyes. It is less widely known, but also well established, that limited stereopsis is constructed from multiple viewing positions over time, in each individual eye, utilizing saccadic movement.

We have discovered that the brain also can construct stereo imagery from multiple images projected simultaneously to a single eye, as long as they are all in focus and coordinated for point of view. And, amazingly, these multiple images can be aimed at portions of the retina quite far from the fovea. (This is in contrast with saccadic movement, which—in healthy people—never strays far enough to shine images on areas of the retina at any great distance from the fovea.) Yet even when these multiple images are seen by peripheral areas of the retina, the brain naturally constructs a single full-field stereo image with good visual acuity.

This is counter-intuitive, because the fovea is known to have many times greater distribution of photo receptors than farther-out regions of the retina, and somewhere above 90 percent of normal visual acuity is supplied by the fovea. Most experts therefore suppose that light aimed at peripheral areas of the retina will be perceived only dimly and with severely limited acuity; think of the fuzzy image detail you see when looking as far to the side as possible while keeping your eyes pointed straight ahead.

A few hitherto unknown phenomena are combining here:

a) The brain automatically constructs stereopsis that fills the visual field when we show many in-focus images, each onto small sections of the retina of a single eye. No accommodation time is required. We have, so far, tested up to 49 simultaneous still images and/or video streams per eye. So long as these multiple images are coordinated for the proper viewing angle and projected in full focus at infinity, the viewer sees in stereo with a single eye.
b) The paucity of photoreceptors in peripheral areas of the retina as compared with the fovea would seem to yield very fuzzy images for our method of constructing stereopsis. Yet we show an increase in perceived acuity for each additional stereo view. In our tests, 49 or more views of

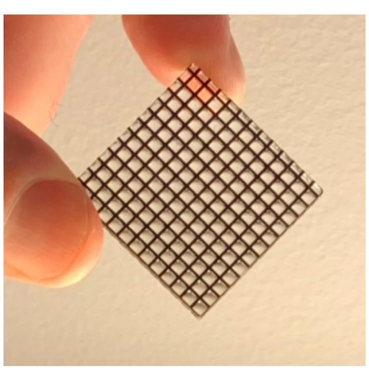
the same basic scene, aimed only at peripheral regions of the retina and including the proper perspective differences for perception from each particular area of the retina used, amounts to an overall image with acuity indistinguishable (in our subjective tests) from the viewer's perception of the same scene aimed only at the fovea. Indeed, it seems that rigorous testing—now ongoing—will prove that these multiple views will achieve significantly better acuity than can be seen in the usual manner, i.e. achieve "hyper visual acuity," or acuity finer than the typical benchmark for healthy sight of one arc minute. (The most famous use case for hyper visual acuity is probably that of many great hitters in baseball, who can see the threads on the ball as it comes at them from the pitcher's hand and determine whether that pitch is a fastball or a breaking ball.)

c) When the brain gets redundant coverage of the same basic visual information, it automatically combines the information. If some area of the overall field of view is lacking any information, the brain patches in that missing information from another view. This works with the multiple in-focus images we can project onto a single retina just as it does with information coming to a person's two eyes. To be sure, this does not work perfectly: if one lacks vision of a large portion of what would be the normal field of view, the information from the other eye can't fill in all of what's missing. What do we mean by "a large portion"? That seems, so far in our testing, to be different for each test subject. More testing here is required.

d) Given the above phenomenon, our software can purposefully black out all information that would hit a given area of the retina which is diseased in some way that may normally cause distortions in a person's sight, while projecting redundant information covering that portion of the overall visual field to other areas of the retina, and the viewer will see a full-field image that does not feature any of the distortions present in the now unused areas of the retina. As noted above, this works up to some limit, which we believe is likely to be slightly different for each person. Beyond that limit, too much information is missing for the brain to be able to fill in what's missing from the given redundant information registering elsewhere on the retina.

Our first use of these discoveries is to fill in the faulty areas of the visual field experienced by people living with macular degeneration (MD), thus presenting a full and accurate visual field to many users. There are many other uses, including inducing hyper visual acuity (not only highly useful in baseball, but also likely to be helpful for warfighters, surgeons and many other occupations); creating a superior competitor to optical coherence tomography; creating far more accurate gaze tracking than currently available and that would be optimal for high-speed instrument control, and more.

2. How We Do It



***The SolidddVision lens*.**

We made our discoveries because we invented a tool: a "Stanhope-plenoptic" lens array. We call this the SolidddVision™ lens. The patented SolidddVision lens is an array of Stanhope lenses, tightly packed and optimized for the largest possible size per lens in the array and the least distortion and crosstalk between lenses. It's a "plenoptic," or fly's eye lens array, with each lens being a Stanhope. Each Stanhope lens offers a view to the eye, or to a camera, that is in full focus at infinity. Stanhope lenses are like pinholes in that the diameter of the aperture and exit pupil are smaller than the diameter of the eye's natural lens (essentially the size of the pupil, or the dark area in the center of the iris), so that light passes through unaffected by the eye's natural lens, and images directly on the retina in a parallel ray.

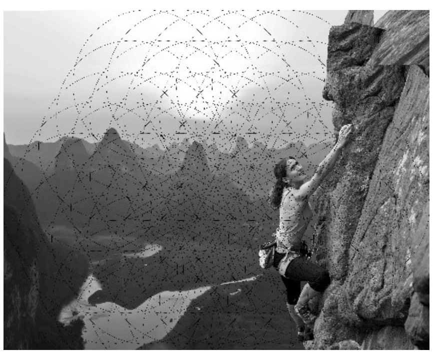
We created this tool in order to take advantage of the trend of ever-increasing resolution in small displays. The lens array we use now is only about 3mm thick and could be made thinner, so it rivals widely available waveguide systems for minimal bulk in front of the user's eyes. It is far superior to other alternative near-eye lens options for thickness and weight. At a typical distance from the eye, it offers an unrivaled field of view: well over 90 degrees depending on the size of the lens array and underlying display or displays, compared with at most 40 degrees for waveguide systems. However, when the plenoptic array is fitted over a display, the resolution of each lens in the array equals the display's resolution divided by the number of lenses in the array. Even with the additive effect in apparent resolution discussed above, a plenoptic array necessitates lower perceived resolution than other alternative lens designs per the same field of view. But the resolution and the number of pixels per inch for the various display technologies used in near eye systems continues to increase. When we wrote up our first patent on our optics, mass-produced small displays featured "pixel pitch" (i.e., the distance from center to center of each pixel in a display) of 20 microns at best. We assumed at that time that we needed to get to 1 micron pitch in order to lose the "screen door effect," that is, the appearance of pixel blocks in video shown on the display. By late 2024, the best full-color displays available offer pixel pitch of about 6 microns. One micron pitch is clearly on the horizon. And, because of the additive increase in perceived resolution that we have observed, we expect that the pixel pitch needed to avoid the screen door effect will be around 3 microns.

When we invented the SolidddVision lens, we called our system a "Foveal Display." We assumed that all the light from our multiple lenses needed to be trained on the fovea. Instead, we found that light from the peripheral lenses in the array inevitably aimed at retinal areas far from the fovea. Indeed, the closer to the eye that the lens array is positioned, the farther from the fovea we aim our imagery. And, realizing this, we began to understand the single-eye stereopsis effects discussed above.

Reference image used in our proof-of-concept. Imagine this is the view you may be looking at through SolidddVision glasses.

Reference image showing view (circle) of a single lenslet in the SolidddVision lens array.

Reference image showing over-lapping views of two lenses (the two circles) in the SolidddVision lens array.

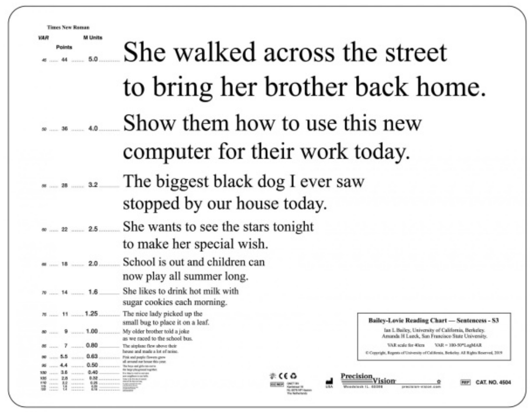


Reference image showing over-lapping views of all lenses in the SolidddVision lens array.

Actual content behind 2 successive lenses in the SolidddVision lens array.

3. Pre-Clinical Trials for Correcting Sight of People Living With MD

Once we began to understand single-eye stereopsis, we guessed that we might use our lens array to help people who live with MD. We tested this theory on a few people and found very promising results. William Seiple, Ph.D., chief research officer at Lighthouse Guild in New York City (https://lighthouseguild.org), agreed to become our principal investigator as we set out to establish firm quantitative data on the system's effects on tested subjects. Once he attained some familiarity with the capabilities of our prototype, Dr. Seiple devised a testing protocol.



A Bailey Lovie reading chart.

We tested subjects for comparative reading speed, both through our system and via the normal way the test subject reads. This quantified the improvement in the subject's sight by timed reading of a modified Bailey Lovie low vision reading chart of scrambled words. (Our modification was simply to use fewer words and only a large font—such as the top line in the illustration—because our subjects' natural reading ability was not good enough to read a full page.) We showed the subjects equivalent, but different scrambled words, so that memory of the first reading didn't contaminate the second test, and we showed them such that both the "normal" reading and that through our lens took up the same approximate visual angle.

Inclusion criteria were simply subjects with MD who have experienced central vision loss. Subjects were excluded for the following reasons:

- Subjects with either complete blindness or peripheral vision loss.
- Subjects who do not benefit from magnification.
- Subjects who have had ocular surgery other than uncomplicated cataract surgery.
- Subjects with multiple eye diseases.
- Subjects who are unable to correctly align with and get close to Soliddd's demonstration lens.
- Subjects who have cognitive impairment.
- We excluded tests on subject's second eye test. Only one eye test per subject was considered valid, as we were testing brain functionality along with the eye.

We tested 31 qualified subjects. The procedure with each was:

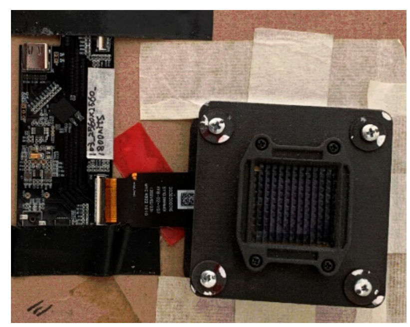
1. A brief interview determined the subject's general level of visual impairment with MD, and age and gender data as well as which is their "better" eye.
2. Subjects told us their own subjective understanding of their current functional reading difficulty by answering the following question: How difficult is it for you to accomplish near reading with your current reading prescription (or no prescription glasses if they wear none) on a scale from 0 to 5, with 0 being none, 1 little difficulty, 2 somewhat difficult, 3 difficult, 4 very difficult, 5 extremely difficult. Then the same question was asked again, this time for when they use their current low vision magnifier or magnifying device.

3. Subjects looked at an image through the Soliddd lens with what they consider their better eye to accustom themselves to looking through it. This is because we preferred them to position themselves to the prototype with a very short vertex distance (the distance from the cornea to the surface of our lens); the closer to the eye, the more our optics aim light to the far periphery of the retina.
4. Subjects read text from a Bailey Lovie chart with and without any eyeglasses they may normally wear, at distance of 40cm, each showing different Bailey Lovie word scrambles. If they are comfortable reading at a different distance, they do so again at that distance. The time of each reading was recorded and we logged their fastest time.
5. Subjects then looked into the Soliddd prototype at a different subset of the Bailey Lovie chart words that is appropriate for their level of visual acuity, and at a size such that it fills the visual field equally with the overall angle of view of the text at their previously logged fastest time. Their reading speed with the Soliddd prototype was recorded.

This series of tests was conducted at multiple sites around the U.S., with the cooperation of several ophthalmologists' and optometrists' offices and low-vision clinics.

Our results showed SolidddVision improves reading speed typically by at least 50 percent and often by a great deal. In detail, the breakdown of the total number of subjects' responses is:

- Read faster normally than with SolidddVision: 4 patients
- Read at approximately the same speed either way: 2 patients
- Read faster than normal reading by between 50% and 99%: 6 patients
- Read 2x to 3x faster than normal reading: 2 patients
- Read 4x to 9x faster than normal reading: 4 patients
- Read 10x or more faster than normal reading: 6 patients
- Read infinitely faster (i.e. subject could not read at all normally but could with SolidddVision): 7 patients



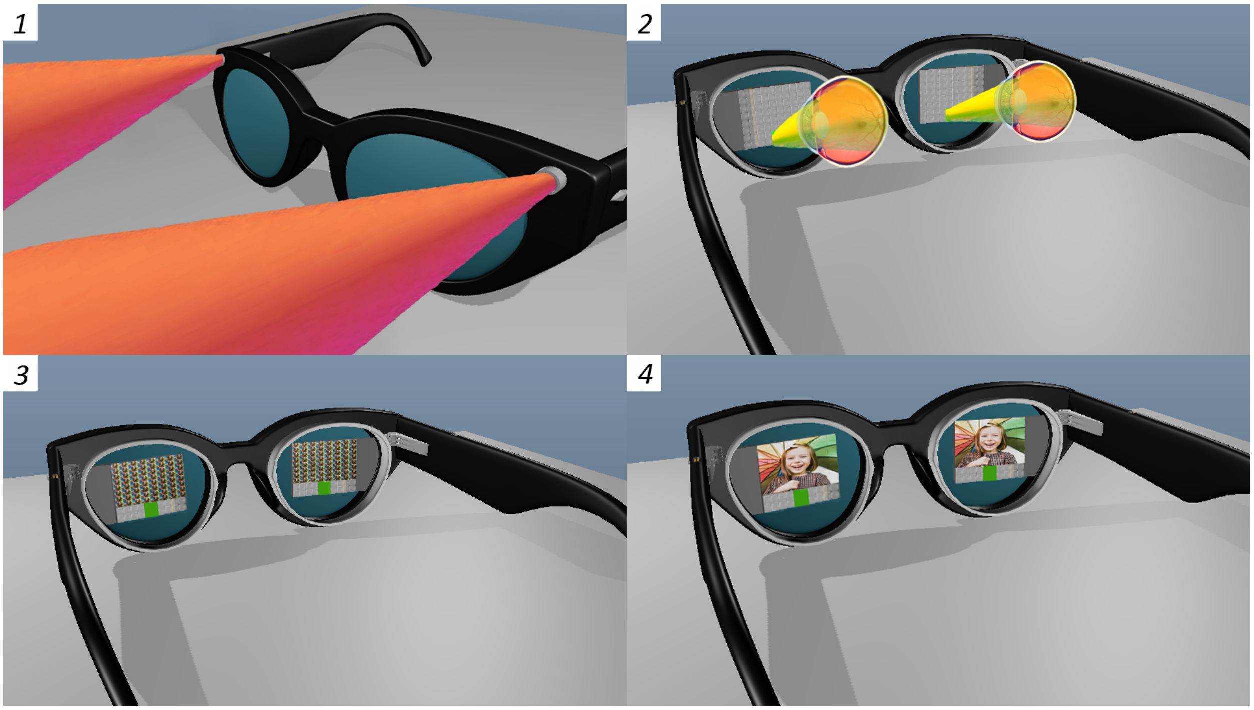
SolidddVision monocular prototype used in patient tests.

Of those we failed to help with our prototype, all four subjects who read faster normally had advanced atrophy and read only at extremely slow speed in either way; and both of the subjects who read at about the same speed either with our prototype or normally could read easily normally, so that reading with SolidddVision offered no measurable improvement.

The results were quite clear: for most people with central vision loss due to MD, SolidddVision offered a strong improvement in their ability to read.

4. Future Testing with Full SolidddVision Glasses

The test results cited here were achieved using our PC-tethered monocular prototype. We were only able to use video or photos that had been recorded and were shown from a Windows computer, with all Soliddd software running on that computer. We were only able to test a single eye at a time (though—as previously mentioned—we only wanted to test one eye per subject). We used a 1cm-wide Sony OLED display with pixel pitch of about 9 microns and a total of 9 Soliddd SolidddVision lens tiles engaged for the first few tests, and a See Ya display that is about 1 inch square with about 7 micron pitch and a total of 49 Soliddd SolidddVision lens tiles engaged for most tests.



SoliddVision glasses will allow people with macular degeneration to see the full normal visual field with good acuity by: (1) using two forward-facing video cameras to capture the world; (2) two inward-facing video cameras simultaneously map the inside of the eye for accurate automatic universal fit and gaze tracking; (3) software instantly processes incoming video with gaze tracking input and proper angle of view adjustment for stereo vision, correction for chromatic and spherical aberration, and other issues, and sends over 100 distinct views to two inward-facing displays behind SolidddVision lenses; (4) the viewer's brain then automatically brings together the separate images to construct a single, full-field 3D, sharply focused image for each eye.

Further and far more detailed tests are planned with the first generation of SolidddVision glasses, to be introduced in 2025. Those glasses will have a total of over three times the number of lens tiles compared with the 49 tiles used in our patient tests so far; that improvement alone is expected to offer a great improvement in performance. And with those glasses we will enable our parallel ray optics to accurately measure the geometry of each user's eyes unobtrusively while they are using the glasses. That will not only give us excellent gaze tracking, but will allow us to locate scotomas and other damage to the eye, and allow us adjust the light we project per specific tiny regions of the eyes, for each user accordingly. So we believe our effectiveness in restoring normal sight should be significantly greater than our test results so far.

For more information, contact info@soliddd.com.

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